I – Problem Statement Title (EQ 001)

Multiple-Support Response Spectrum Analysis of Bridges

II – Research Problem Statement
Question: In assessing the seismic demand on a bridge, when and how shall we account for the effect of differential support motions?

Differential support motions can increase the seismic demand on a bridge. Factors giving rise to such motions include wave passage, wave incoherence and spatially varying soil profiles. For an improved understanding and characterization of the seismic hazard, there is need for a simple method of dynamic analysis that accurately accounts for these effects, and a quantitative criterion that describes conditions under which such analysis is necessary. A simple method to account for nonlinear behavior is also needed.

III – Objectives
STAP Roadmap Outcome: 7 - Improved Understanding of Seismic Hazards.

1. Develop a better understanding of the spatial variability of both far-field and near-field ground motions.
2. Develop a quantitative criterion for determining conditions under which it is necessary to consider the effect of differential support motions in assessing the seismic demand on a bridge.
3. Develop a simple, response spectrum-based method for dynamic analysis of multiply supported bridges accounting for differential support motions arising from wave passage, wave incoherence and spatially varying soil profiles.
4. Assess the effect of spatial variability for near-field ground motions.
5. Explore simple methods to account for nonlinear bridge behavior on the displacement demand under differential support motions.

IV – Background
Differential seismic motions at the support points of a bridge may arise from four distinct effects: (a) the effect of wave passage, which is due to the difference in the arrival times of waves at the support points, (b) the effect of incoherence, which is due to the inhomogeneity in the travel paths of waves as well as the extended nature of the source (waves from different segments of the source superimpose differently at each support point), (c) the effect of varying soil profiles along the bridge and the differential manner in which they modify the vertically propagating waves from the bedrock at each support site, and (d) the effect of intensity attenuation due to geometric spreading and energy dissipation of seismic waves. The wave passage and incoherence effects tend to grow with increasing distance between the support points, whereas the site response effect is influenced by the rate of variation in the soil profile along the bridge. For near-field ground motions, the effect of incoherence can be especially large due to proximity to the

extended source. Previous studies have shown that the attenuation effect is not important and can be neglected.

At the present time, Caltrans' Seismic Design Criteria (SDC) requires consideration of "non-synchronous" ground motions and the impact of varying subsurface profiles for bridges exceeding 1000 ft (300 m) in length. No simple method of analysis is provided. In practice, typically time history analysis with recorded or simulated ground motions is performed. However, this type of analysis is costly, especially if repeated design modifications are to be made. Furthermore, the results are specific to the selected set of ground motions, which may not be consistent or compatible with the design spectra.

Long-span bridges, such as suspension or cable-stayed bridges, are typically compliant structures which tend to "ride along" with differential support motions. Differential support motions in such structures tend to reduce the response relative to that under uniform support motions. On the other hand, short-span bridges are typically rigid structures and even small variability in their support motions could induce large internal forces. Thus, the length of the bridge or its spans should not be the only criterion in deciding when to perform differential support motion analysis. Other factors, including the flexibility of the bridge and the distance to the earthquake source, should also be considered.

In this research, a simple, response spectrum-based method will be developed that accurately accounts for the effects of wave passage, incoherence and varying site response. The method will be an extension of the CQC modal combination rule already in use by Caltrans. By performing a parametric study, quantitative criteria will be developed that determine conditions under which consideration of spatial variability is necessary. Special attention will be given to near-field ground motions. These criteria will be formulated in a simple form appropriate for specification in Caltrans' SDC.

For design purposes, the effect of nonlinear behavior on the displacement demand must be determined. Simple rules will be developed to account for this effect in the response-spectrum analysis for differential support motions. In particular, it is desirable to check the validity and limitations of the equivalent displacement rule commonly used for ordinary buildings. Other approximate nonlinear analysis methods, such as equivalent linearization, will be investigated.

V – Statement of Urgency and Benefits
Accurate and simple methods for dynamic analysis under differential support motions will lead to improved characterization of the seismic hazard and safer and more economical bridge designs. The Caltrans SDC is in urgent need of a quantitative criterion that correctly determines conditions under which consideration of differential support motions is necessary.

VI – Related Research
Methods for response spectrum analysis of buildings and multiply-supported structures have been developed at UC Berkeley in recent past. The proposed research will take full advantage of this work. For investigation of the incoherence effect in near-field ground motions, use will be made of recorded as well as simulated ground motions, including the Caltrans-funded simulations being developed by D. Dreger at UC Berkeley.

VII – Deployment Potential
The proposed research will help improve the Caltrans provisions for analysis and design of bridges, including the specifications in SDC.